Lab 2

Daisyworld

Biological homeostasis of the global environment

Introduction

Welcome to Daisyworld – a cloudless world with only negligible atmospheric greenhouse gases and only two species of daisy for life. One of these species is dark, the other is light. These two species we will refer to as "black" and "white" although neither species needs to be perfectly black or white. Despite its simplicity in many ways Daisyworld is similar to our own.

In this lab we will explore how the two species of plants exhibit a strong influence on the global temperature of this planet. As we will see, even in this relatively simple world there is a wonderful amount of complexity.

Daisyworld was invented by James Lovelock in response to criticism over his idea of Gaia – that being that living organisms can control their global environment. The concept of Gaia is fully described in Lovelock (1979). Here we will deal only with Daisyworld; the mathematics of which are described in Watson and Lovelock (1983).

Daisyworld is fairly simple to describe. The "black" and "white" daisies have two albedos, and bare ground a third. These three land surfaces each cover a certain fraction of the planet. In addition, there is only a certain fraction of the surface that fertile where daisies can grow. Daisies also die at a certain rate. The outside energy controlling the configuration of Daisyworld is of course the sun and its value is expressed as a fraction of the current solar output.

There are two 'hidden' quantities as well. First, Daisies grow at a fixed rate which dependant on the surface temperature above the daises. Secondly there is a parameter that relates local temperature to local albedo, since we would expect temperatures over the "black" daisies to be higher than those over the "white." In essence this quantity redistributes the energy absorbed by the surface among the three cover types. Also, daisies only exist at local temperatures between 5 and 40° C.

The nuts and bolts of the lab

This lab is designed using Microsoft Excel97. It is adapted from a BASIC program designed by K. McGuffie and A. Henderson-Sellers. The mathematics describing Daisyworld are captured in two Visual Basic functions: *Daisyworld_Calculations* and *Daisyworld_non_equilbrium*.

The *Daisyworld_Calculations* function will determine the equilibrium global temperature of Daisyworld and the equilibrium fractions of black and white daisies and bare ground for a given set of conditions.

Then *Daisyworld_non_equilbrium* function will calculate the global temperature and fractions of black and white daisies at a certain time. To achieve equilibrium, it is necessary to run the function numerous times, using the albedos produced from the previous run until equilibrium is reached

There are two worksheets in the Excel workbook, one for each of these functions. A more detailed description of the functions is given in the spreadsheet.

These functions are written in Visual Basic and can be viewed by selecting Macros under the tool menu and then selecting the Visual Basic Editor (or type Alt+F11). Because of the use of these functions, this spreadsheet will not run under other versions of Excel or other spreadsheets – Sorry.

References

Lovelock, J. E. 1979. Gaia: a new look at life on Earth. Oxford University Press, Oxford, 157pp.

McGuffie, K. and Henderson-Sellers, A. 1997. A Climate Modelling Primer. John Wiley & Sons, Chichester, 253pp

Watson, A.J. and Lovelock, J.E. 1983. Biological homeostasis of the global environment: The parable of Daisyworld. Tellus 35B. 284-289.

Questions

1a) Using the Equilibrium Solutions Worksheet produce a graph showing the GLOBAL TEMPERATURE for a “dead” Daisyworld – that is one with no daisies, and an surface albedo of 0.5 – as a function of SOLAR LUMINOSITY ranging between 0.5 and 2.5.

1b) Produce a graph as in 1a expect for a “live” Daisyworld with the following parameters:

Albedo_black	0.25
Albedo_white	0.75
Albedo_ground	0.5
Daisy_death_rate	0.3
Solar_luminosity	0.5 to 1.0
Fertile_fraction	0.75

1c) Do the Daisies have an affect on the temperature of Daisyworld? If so what is it?

1d) Is there anything in this simple experiment that you might not expect (try raising the fertile_fraction to 1.0 to enhance the effect and if you still are not sure try reading through the Watson and Lovelock article)?

1e) What is the effect of “black” daisies on the global temperature? Of “white” daisies?

1f) Produce a graph identical to (1b) but showing the GLOBAL TEMPERATURES as a function of SOLAR ILLUMINOSITY for fertile_fractions of both 0.5 and 1.0. What is the effecting of increasing the amount of vegetation? Does vegetation appear to have a stabilizing influence on the 'climate' of Daisyworld?

Now let's turn to the non-equilibrium case – it is on the other worksheet

2a) With the following parameterization, what is the final equilibrium temperature of Daisyworld?

albedo_black	0.25	Area_black	0.33333
albedo_white	0.75	Area_white	0.33333
albedo_ground	0.5	Area_ground	0.33333
daisy_death_rate	0.3		
solar_luminosity	1.0		
fertile_fraction	0.75		

2b) Now adjust the values of Area_black, Area_white, Area_ground to (0.8, 0.1, 0.1). What is the new equilibrium temperature? Has the system evolved (in terms of temperature and fraction of each cover) in the same manner as in (2a)?

2c) Now try a few other combinations of the Areas (make sure they sum to 1). Short of making one or more species of daisies extinct, can you change the final equilibrium temperature? Is the behavior of Daisyworld transitive or intransitive with regard to the starting cover fractions?

2d) Now reset the values to those in 2a. Try adjusting the fertile_fraction. Is the behavior of Daisyworld transitive or intransitive with regards to the fertile_fraction?

Now let's have some fun and have Daisyworld experience a catastrophic bolide (asteroid) impact.

This can be accomplished by killing off 90% of each species of Daisy at time=5. Examine the spreadsheet so you understand what is being passed into the function at each timestep. This should give you some idea of how to change the variables to accomplish the mayhem. [Hint: I accomplished this by inserting a single number into two cells at time=5].

Believe it or not, this destruction is not as evasive as the extinction that happened on Earth at the end of the Permian Period when approximately 99% of all species became extinct.

3a) With the following parameters, does it appear Daisyworld will fully recover from this catastrophe (e.g. will the temperature return to pre-impact values and do the Daisy's recover)?

albedo_black	0.25	Area_black	0.33333
albedo_white	0.75	Area_white	0.33333
albedo_ground	0.5	Area_ground	0.33333
daisy_death_rate	0.3		
solar_luminosity	1.0		
fertile_fraction	1.0		

3b) Now let's turn up the heat on Daisyworld (increase the solar_luminosity to 1.2) and repeat our impact experiment. Does Daisyworld fully recover from this catastrophe, why or why not? [Note that the temperature might not have reached equilibrium by time of the meteor impact at time=5. In the equilibrium version of the model, I set it up to iterate up to 100 times to achieve equilibrium so this is not surprising.]

3c) If the daisies can survive temperatures of up to 40° C, why did we manage to kill off the “black” daisies while the white ones survived when *global* temperatures never exceeded 40° C?

3d) Does it appear to always require two daisy species to regulate the temperature of Daisyworld?

3e) Let's push the envelope a little farther. Let's hike the solar_luminosity up to 1.3. Compared to the “white” daisies response at a solar_luminosity of 1.2, how quickly do they recover (in terms of population)? Does this appear to be biologically realistic, why or why not?

3f) Let's go just a bit farther. Up the solar_luminosity to 1.305. Now what happens?

Now lower the solar_luminosity to 1.303. Now what happens?

What is finally exceeded at 1.304?

By comparing the population curves for solar_luminosities of 1.300, 1.301, 1.302, 1.303, would you predict the outcome at a solar_luminosity of 1.304? Why or why not?

What does this behavior of a simple system such as Daisyworld, suggest about our ability to predict the behavior of a more complicated system such as the Earth?

Extra Credit) Okay now it is your turn to try working on the spreadsheet.

On the non-equilibrium sheet below the first set of calculations I have placed, two columns. The first is time, just like above. The second is a time varying solar luminosity.

What I would like you to do is to calculate and plot the temperature and cover changes over time, just as like above, except now the solar_luminosity varies at each time step. You should be able to use the calculations above as a guide. Remember, however that the calculations for each time step are dependent on the time before. I would like to see your graphs (use the same calculations as in 3a). If you are really ambitious you might try and see what happens if you impose an extinction event on top of time varying solar illumination

Lab Evaluation

Once again it is your turn to evaluate me. This is totally optional, but your feedback is important to help me improve the labs and my performance. Also, if you prefer you can hand it in separately and maintain your anonymity.

On a scale of 1 (cow dung) to 5 (Fillet Mignon)– apologizes to the vegetarians in the group, but I am from Iowa – please rate this lab.

1 2 3 4 5

How worthwhile was it?

1 2 3 4 5

How long did it take you to complete the lab?

What did you like about the Lab?

How can it be improved?

Any other comments?